TITLE: WASTEWATER TREATMENT SYSTEM

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BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The invention pertains to systems for treating wastewater and, more particularly, to an apparatus and method for treating wastewater on marine vessels, or land-based systems, so the effluent can safely be released into the environment.

Description of the Prior Art

[0002] Wastewater generated on marine vessels such as ships, ferries and pleasure craft should be treated before it is released into the marine environment to prevent or reduce environmental contamination. This wastewater can include waste from toilets, sometimes referred to as "blackwater", waste from showers, sinks, laundry machines, galleys and the like, sometimes referred to as "greywater," and bilge water. In many jurisdictions, the standards for wastewater effluent discharge from marine vessels is prescribed by government regulation. The standards may limit

the discharge of suspended solid, contaminants affecting BOD (biochemical oxygen demand) and pathogens. Hence, effluent treatment may involve suspended solids removal, BOD reduction and disinfection.

[0003] Wastewater treatment systems for marine applications typically include the use of disinfecting chemicals such as chlorine or the use of microbiological oxidation. Both systems have disadvantages. Chlorine and similar disinfecting chemicals are themselves environmental contaminants and may form harmful byproducts, such as various chlorinated compounds. They require hazardous chemical storage on the vessel. Their use in marine applications is prohibited in some jurisdictions. Chlorination will only achieve disinfection of the wastewater. Treatment by biological digestion is effective in land-based sewage treatment but is not well suited for marine applications for various reasons. These include the slowness of the process and its sensitivity to influent substances such as surfactants and to changes in salinity, temperature and flow volumes. Biological treatment systems have large footprint requirements. On start-up, time is required for development of the biological growth within the treatment apparatus; this can take several days, resulting in effluent that does not meet discharge limits. The

resultant effluent from a biological reactor may still require the removal of suspended solids and disinfection.

[0004] It is known that ozone can be used for oxidizing the contaminants in wastewater and for disinfection. For example, U.S. Patents 4,197,200 (Alig) and 4,053,399 (Donnelly et al.) describe wastewater treatment systems in which ozone gas is employed. However, the use of diffusers to introduce the gas into wastewater will not achieve the micro-bubble size for effective solids removal in dissolved gas flotation nor the efficient reduction of BOD via oxidation of the contaminants. In addition, the diffusers can plug with solids during system shutdown, rendering system maintenance difficult.

SUMMARY OF THE INVENTION

[0005] The invention provides an apparatus and method for treating wastewater (which can include blackwater, greywater and/or bilge water in marine and land-based applications) that uses ozone as an oxidizing agent and does not rely on microbiological oxidation or involve the use of any additional disinfecting chemicals. The system effectively reduces the BOD, total suspended solids (TSS) and fecal coliform count of the discharged water so it can be released into the environment to meet

effluent regulations. The system includes a solids separation tank, an oxidation tank preferably having a plurality of chambers and a fluid circuit for re-circulating treated wastewater into the oxidation tank and, preferably, also into the solids separation tank, for further treatment. Suspended solids are separated by dissolved gas flotation and the wastewater is oxidized by ozone that is dissolved in the treated wastewater (effluent) and re-circulated through the treatment apparatus. Although solids separation takes place mainly in the solids separation tank it will also take place in the oxidation tank. Oxidation takes place in all the chambers. Advantageously, the introduction of ozone into the system as a gas which is dissolved in the effluent and is subsequently released from solution in the reaction vessels via nozzles to form a gas used for flotation and oxidation avoids the use of diffusers to introduce ozone as a gas. A high degree of BOD removal is achieved in this system. The ozone used in the system is generated on the vessel (in the case of marine applications) using electricity produced by the vessel's engines, so no transporting or storage of tanks of chemicals is required. In the case of difficult to oxidize chemicals such as certain surfactants and oil, advanced oxidation technologies may be included. Advanced oxidation technologies are those that produce hydroxyl radicals which are very aggressive

oxidants. One means of producing these radicals is via the exposure of ozone to ultraviolet light.

[0006] According to the present invention, there is provided an apparatus for treating wastewater comprising: a wastewater inlet conduit; a solids separation tank to receive wastewater from the inlet conduit, for the separation of solids from liquid in the wastewater; an oxidation tank in fluid communication with the solids separation tank to receive liquid from the solids separation tank; a liquid outlet conduit from the oxidation tank to conduct liquid from the oxidation tank; a source of gas comprising ozone; means for dissolving the gas comprising ozone in liquid from the liquid outlet conduit; a re-circulating circuit for conducting the liquid with dissolved gas comprising ozone to the solids separation tank and the oxidation tank; discharge means for discharging the liquid with dissolved gas comprising ozone into the solids separation tank and oxidation tank, whereby the dissolved gas comprising ozone forms gas bubbles in the solids separation tank and oxidation tank; and a liquid discharge conduit to discharge treated liquid from the apparatus.

[0007] In accordance with another aspect of the invention, there is provided an apparatus for treating sewage comprising: a wastewater inlet conduit; a solids separation tank to receive the wastewater from the inlet

conduit, with gas distribution means therein for the separation of solids from liquid in the wastewater by gas flotation; an oxidation tank in fluid communication with the solids separation tank to receive liquid from the solids separation tank; a liquid outlet conduit from the oxidation tank to conduct liquid from the oxidation tank; a source of gas comprising ozone; means for dissolving the gas comprising ozone in liquid from the liquid outlet conduit; a re-circulating circuit for conducting the liquid with dissolved gas comprising ozone to the oxidation tank; discharge means for discharging the liquid with dissolved gas comprising ozone into the oxidation tank, whereby the dissolved gas comprising ozone forms gas bubbles in the oxidation tank; and a liquid discharge conduit to discharge treated liquid from the apparatus.

[0008] In accordance with yet another aspect of the invention, there is provided a method for treating wastewater comprising the steps of: providing a treatment system comprising a solids separation tank, an oxidation tank and a liquid flow circuit whereby liquid flows from the solids separation tank into the oxidation tank, out of the oxidation tank and is reintroduced into the solids separation tank and the oxidation tank; dissolving a gas comprising ozone into the liquid in the liquid flow circuit after the liquid exits from the oxidation tank; introducing wastewater to be

treated into the solids separation tank; separating solids from liquid in the wastewater in the solids separation tank; allowing the liquid from the solids separation tank to pass into the oxidation tank; introducing the liquid with dissolved gas comprising ozone into the liquid in the oxidation tank and allowing the gas comprising ozone to form bubbles in the liquid in the oxidation tank and cause oxidation of substances in the liquid in the oxidation tank; and removing treated liquid from the treatment system for discharge to the environment.

[0009] In accordance with yet another aspect of the invention, there is provided a method for treating wastewater comprising the steps of: providing a treatment system comprising a solids separation tank, an oxidation tank and a liquid flow circuit whereby liquid flows from the solids separation tank into the oxidation tank, out of the oxidation tank and is reintroduced into the oxidation tank; dissolving a gas comprising ozone into the liquid in the liquid flow circuit after the liquid exits from the oxidation tank; introducing wastewater to be treated into the solids separation tank; separating solids from liquid in the wastewater in the solids separation tank by means of gas flotation; allowing the liquid from the solids separation tank to pass into the oxidation tank; introducing the liquid, with dissolved gas comprising ozone into the liquid in the oxidation

tank and allowing the gas comprising ozone to form bubbles in the liquid in the oxidation tank and cause oxidation of substances in the liquid in the oxidation tank; and removing treated liquid from the treatment system for discharge to the environment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Figure 1 is a schematic view of a wastewater treatment apparatus according to the invention; and

[0011] Figure 2 is a cross-sectional view of a discharge nozzle.

PREFERRED EMBODIMENT

[0012] Wastewater treatment apparatus **10** comprises, in general terms, a solids separation tank **12**, oxidation tank **14**, ozone source **16**, ozone distribution devices or nozzles **84**, optional ozone destructor **94**, optional advanced oxidation system **96,** solids removal system (not shown) and associated conduits, valves and pumps. The apparatus provides for the continuous re-circulation of a portion of the treated wastewater back into the apparatus for further treatment. Alternatively, the system can be configured for a single pass mode operation.

[0013] Inlet conduit **18** conveys wastewater from a wastewater source **20** which, on a ship, can be the toilets, sinks, showers, laundry, galley, bilge, etc. of the ship, into solids separation tank **12.** Option- ally, a grinder (not shown) can be provided in conduit **18** to grind solid matter in the wastewater prior to its entry into the solids separation tank. Likewise, a screen can optionally be provided in conduit **18** to remove solids from the influent. An optional holding tank can also be provided between the wastewater source **20** and the solids separation tank.

[0014] The wastewater enters the solids separation tank **12** through T-shaped receiving duct **15,** which is open at its upper and lower ends in the solids separation tank. The incoming wastewater is immediately contacted with ozone from nozzle **84** located just below the lower end of the T-shaped receiving duct. A dissolved gas flotation process is carried out in the solids separation tank **12**, as described below, to effect substantial separation of suspended solids in the raw wastewater. This process forms a solids cap **22** floating on the liquid portion **24** of the wastewater. This cap will be at least partly digested by the gas which consists mainly of oxygen and ozone. This digestive action will result in a reduced rate of solids accumulation in comparison with standard dissolved air flotation. The cap may be removed on an intermittent or continuous

basis. Heavy solids that are not floated to the surface sink to the bottom of the solids separation tank **12**, forming a mass **26.**

[0015] Oxidation tank **14** preferably comprises three chambers, namely inlet chamber **28**, intermediate chamber **30** and outlet chamber **32**. The oxidation tank may have fewer or more than three chambers. The solids separation tank and oxidation tank are preferably constructed as a single, integral unit. Inlet chamber **28** is separated from solids separation tank **12** by wall **34.** Conduit **36** passes through wall **34,** permitting the flow of both gas and liquid from the solids separation tank into chamber **28** of the oxidation tank **14.** Conduit **36** is a generally H-shaped structure, having an upper duct **38** in the solids separation tank that extends above the solids cap **22** and opens into headspace **40** in the solids separation tank, and an upper duct **42** that opens into the headspace **44** in chamber **28.** A conduit **39** is also provided between tank **12** and chamber **28** as a safety feature in the event that duct **38** becomes covered or blocked with solids. Gas can accordingly flow between the respective headspaces. Conduit **36** also has lower duct **46** in the solids separation tank and lower duct **48** in inlet chamber **28,** opening below the surface **50** of the liquid **24** and accordingly permit-ting the flow of liquid (i.e. wastewater) from the solids

separation tank into chamber **28.** In addition, conduit **36** maintains a constant operating level in the solids separations tank **12.**

[0016] Intermediate chamber **30** of the oxidation tank **14** is separated from inlet chamber **28** and from outlet chamber **32** by walls **52, 54** respectively. Openings **56, 58** are provided in walls **52, 54** respectively near the top of the chambers, above liquid level **50**, to permit the flow of gas in the headspace between the chambers **28, 30, 32.** Likewise, openings **60, 62** are provided in walls **52, 54** respectively, below liquid level **50**, to permit the flow of liquid from inlet chamber **28,** through intermediate chamber **30** and into outlet chamber **32.** Preferably, openings **60** and **62** are arranged near the opposite sides of the oxidation tank (i.e. in and out of the plane of the paper in the view of Figure 1 to provide a sinuous flow path for liquid through the oxidation tank. Wall **108** provides one final over and under pattern prior to liquid exiting the tank through conduits **64** and **104.**

[0017] Liquid outlet conduit **64** leads from the lower part of outlet chamber **32** to pump **66**. Conduit **64** may also include a strainer (not shown) to protect the pump. Conduit **64** includes T-junction **68** to receive gas containing ozone from ozone source **16.** The gas may be introduced at ambient pressure, at elevated pressure or reduced pressure. The pump **66** should be capable of pressurizing water with entrained gas without

causing cavitation or vapor lock. Suitable air handling pumps include regenerative turbine and special multi-phase centrifugal pumps which can handle limited air injection (10-20% v/v).

[0018] An ozone generator is required capable of generating a high percentage of ozone. The preferred gas feed should contain a high level of oxygen. The ozone source **16** comprises ozone generator **70** with associated chiller **72**, or another appropriate cooling device, oxygen concentrator **74** and air compressor **76.** Ozone generator **70** is a preferably a corona discharge-type generator. The feed gas used for ozone generation is oxygen produced by concentrator **74**, which is preferably a pressure swing absorption-type oxygen concentrator. Preferably, the output of the concentrator is about **95%** oxygen. The air compressor **76** supplies compressed air to the concentrator. It is to be understood that the concentrator can include an internal compressor rather than a separate unit. Further, the ozone generator **70** can produce ozone without any oxygen concentrator, but the concentrator permits a smaller capacity ozone generator to be used, which is advantageous for marine applications. The output of ozone generator **70** is gas comprising about 6 - 18% ozone and the balance oxygen, with small quantities of nitrogen and the other gasses normally present in air. The gas containing

ozone passes through conduit **78** and T-junction **68**, where it mixes with the liquid stream in conduit **64** from the oxidation tank, and into pump **66.**

[0019] Pump **66** mixes and pressurizes the liquid and gas mixture and dissolves most of the gas in the liquid. Alternatively, instead of a single re-circulation circuit, some or all of the oxidation tank chambers may be fitted with dedicated re-circulation systems complete with ozone addition. This would give additional process control, however, at a higher cost. Re-circulation conduit **80** conducts the liquid with gas from the pump **66** back into the solids separation tank and the oxidation tank. Conduit **80** passes through the headspace in the oxidation tank and through wall **34** to the solids separation tank and into a downwardly- extending conduit **82** in the solids separation tank **12** and in each chamber of the oxidation tank **14**. Optionally, two or more conduits **82** can be provided in the solids separation tank and in each chamber of the oxidation tank. Conduits **82** end in a discharge means or nozzle **84** below the liquid level in the solids separation tank and the oxidation tank. The liquid and dissolved gas in re-circulation conduit **80** enters the liquid in the solids separation tank and the oxidation tank through nozzles **84.** The pressure in the re-circulation conduit **80,** caused by pump **66,** is higher than the pressure in the solids

separation tank and the oxidation tank. Preferably, the pressure in the re-circulation conduit **80** is about **100** psi and that in the solids separation tank and oxidation tank about atmospheric. When the liquid with dissolved gas exits the nozzles **84**, much of the dissolved gas with ozone accordingly comes out of solution and forms micro gas bubbles. The appearance of these gas bubbles resembles the formation of smoke clouds. The bubbles should be uniformly distributed throughout the tanks with minimum large bubble formation. Some dissolved gas remains dissolved. Thus, a mixture of treated wastewater (effluent), dissolved gas with ozone and gas bubbles exits the nozzles **84** into the solids separation tank and the chambers of the oxidation tank. In the solids separation tank **12**, the bubbles effect separation of suspended solids by gas flotation, a separation method known in the art and sometimes referred to as dissolved air flotation (DAF). The suspended solids are floated to the top of the liquid. In addition to effecting flotation in the solids separation tank, the ozone oxidizes organic compounds in the wastewater. The ozone and oxygen effects protein stripping and also oxidizes organic compounds in the solids cap **22,** thereby reducing the volume of solids **22** for separation. Solids **26** that settle on the bottom of the solids separation tank are removed from the tank during periodic maintenance.

[0020] Referring to Figure 2, in a preferred configuration nozzle **84** consists of a pipe union **81** containing a plate **83** with a small hole **85** in it. Attached to this plate **83** on the discharge side (by means of legs, not shown in this drawing) is a baffle plate **87** having a smaller diameter than the discharge pipe **82**. The distance between these two plates is slightly larger than the diameter of the hole **85**. For example, the plate **83** in a one inch union **81** would have a 9/64 inch hole and a baffle plate **87** about 3/4 inch in diameter placed at about 3/32 inch from the plate **83.** The shape of the baffle plate can be round or more complex. The stream of effluent with dissolved gas hitting the baffle plate generates micro-bubbles. The impact with which these bubbles hit the plate may result in a phenomena called cavitation which will enhance the oxidation process by creating very aggressive oxidation species. A variety of stacks **89** can be attached to this assembly. The stack promotes uniform distribution of the micro-bubbles in the tank. More than one nozzle **84** can be placed on a single pipe.

[0021] Various other configurations of discharge nozzle can be employed, provided that they discharge a cloud of micro-bubbles of gas into the wastewater and enhance the oxidation via cavitation. Such nozzles may

be found in use in commercially available dissolved air flotation equipment.

[0022] Within the oxidation tank chambers, the dissolved ozone and ozone micro-bubbles exiting nozzles **84** cause oxidation of organic compounds in the wastewater **24** within the oxidation tank. The oxidation process causes reduction of BOD and TSS and disinfects the wastewater.

[0023] Any suspended solids in the wastewater that were not separated out in the solids separation tank and that passed into the oxidation tank are there subject to flotation and oxidation. Any floating cap of solids in the oxidation tank or solids that settle to the bottom of the oxidation tank can be periodically removed. A drain hole is provided in the bottom of the solids separation tank and each of the oxidation tank chambers. Conduits **86**, which include closeable discharge valves **88**, lead from the drain holes to conduit **90**, to permit removal of solids **26** and emptying of the solids separation tank and the oxidation tank. Such removal and emptying is performed as part of the periodic maintenance of the apparatus **10**, for example once every few months, and is not part of the regular and substantially continuous operation of the apparatus.

[0024] It is preferable for the efficiency of the oxidation process to introduce into the apparatus **10** more ozone than will be fully consumed by oxidation, causing an excess of ozone in the headspace of the solids separation tank and oxidation tank. Vent **92** is provided in the top of the oxidation tank to conduct the ozone to an ozone destructor **94**. Preferably, destructor **94** is a thermal destructor unit. The exhaust gases from the destructor are vented to the atmosphere. If desired, rather than destroy the excess ozone, in marine applications it can be fed to the exhaust stack of the vessel where it can be used to oxidize compounds in the exhaust and thereby reduce emissions. Alternatively, the ozone could be reused in the treatment system.

[0025] When the wastewater to be treated in apparatus **10** includes greywater, which contains surfactants, or includes bilge water containing oil and grease, it is desirable to include an advance oxidation technology in the apparatus. This can be accomplished, for example, by an ultraviolet radiator acting on the ozone to produce hydroxyl radicals. These radicals are capable of reacting with and breaking down surfactants or other difficult to oxidize organic chemicals. To incorporate this optional feature, conduit **98** forms a parallel loop on conduit **80,** conducting part of the flow in conduit **80** through ultraviolet radiator **96** and back to re-circulation

conduit **80.** Part of the re- circulating liquid with dissolved gas containing ozone is passed through the radiator. Valves (not shown) are provided to regulate the amount of flow through conduit **98.**

[0026] Discharge conduit **100** leads from re-circulation conduit **80** to permit discharge of treated wastewater from the apparatus. Discharge valve **102** is provided in discharge conduit **100.** To discharge treated wastewater, discharge valve **102** is opened, permitting pump **66** to pump liquid out through discharge conduit **100.** The effluent can be discharged from conduit **100** directly into the marine environment. Preferably, discharge valve **102** is an automated solenoid valve that opens and closes when the liquid level in the oxidation tank rises or falls respectively to pre-set heights.

[0027] Preferably, a backup discharge system is provided to ensure that the capacity to discharge the oxidation tank is always maintained. Secondary discharge conduit **104** leaves from outlet compartment **32** of the oxidation tank to secondary discharge pump **106,** capable of pumping liquid out of the oxidation tank through discharge conduit **100.** It is contemplated that secondary discharge pump **106** is actuated when the liquid in the oxidation tank rises above the normal discharge level handled by the primary discharge system. Optionally, pump **106** can be used as

the primary discharge pump, with pump **66** and discharge valve **102** providing a backup discharge system.

[0028] In use, pump **66** is continuously pumping effluent for re-circulation through the system. Influent, i.e. wastewater to be treated, flows into the solids separation tank **12.** Solids are separated as described above by gas flotation and some oxidation occurs. Liquid in the solids separation tank is displaced as more wastewater flows in, causing the liquid to flow through conduit **36** into the first compartment **28** of the oxidation tank. There, oxidation occurs and some suspended solids that may have passed through the solids separation tank are separated out. The liquid passes through opening **60** into the intermediate chamber **30** where further oxidation (and solids separation, if necessary) occurs, and then through opening **62** into outlet compartment **32** where the same process occurs. The wastewater exits the oxidation tank through conduit **64,** is ozonated in pump **66** and is pumped through re-circulation conduit **80** for re-circulation into the solids separation tank and oxidation tank for further oxidizing treatment. Since in-flowing wastewater through inlet conduit **18** causes a displacement in the liquid level in the solids separation tank and a subsequent rise in level in the oxidation tank, the discharge valve **102** is

periodically opened, causing treated liquid to be discharged from the apparatus through discharge conduit **100.**

Example

[0029] A treatment apparatus was provided for marine blackwater as depicted in Figure 1 in which the combined volume of the solids separation tank and oxidation tank is 20 cubic meters. The volume of wastewater influent was 50 cubic meters per day. The retention time of wastewater within the apparatus was approximately four hours. The use of the apparatus reduced the TSS of the sewage from 1,400 mg/1 to less than 20 mg/1, the BOD from 650 mg/1 to less then 30 mg/1 and the fecal coliform count to less then 100 MPN/100 ml.

[0030] Although it is preferred that the solids separation tank **12** include a conduit **82** and nozzle **84** for the introduction of ozonated effluent, in an alternative embodiment ozonated effluent is introduced only into the oxidation tank. A separate air inlet and diffuser or other gas distribution means is then provided in solids separation tank **12** to effect flotation and solids separation in that tank by means of the introduction of air bubbles.

[0031] The apparatus and method of the invention have been described above primarily in relation to applications on marine vessels. However,

the method and apparatus is equally applicable to land-based wastewater treatment systems.

[0032] The preferred embodiments described above are intended to illustrate the principles of the invention, but not to limit its scope. Various other embodiments and modifications to these preferred embodiments may be made by those skilled in the art without departing from the scope of the following claims.